The Coexisting Curve of the Refrigerant HFC 134a: Some Scaling Models

in a Wide Critical Region [1]

E. E. Ustjuzhanin[2,3], B. F. Reutov[2], A.A. Alexandrov ,

M.M. Safarov[3], K. B. Kusubov[2],

ABSTRACT

The object of the work is a scaling form for thermodynamic properties of HFC 134a along the coexisting curve (CC). The experimental P_s,T - data and densities on CC ρ_l and ρ_g were selected in the region from triple point to critical one. Data [1,2] gave a new P_s,T - information in a wide temperature interval including the triple point pressure. There are new ρ_l,ρ_g,T - data in [1,2,3] including results in the vicinity of the critical point The new data gives an opportunity to build equations for the mentioned properties.

Extended scaling equations were chosen for the correlation of measured values. The temperature dependence of the order parameter and the CC diameter were analyzed. A routine for determination of the expressions was elaborated. A system of $P_s\,(T)$, $\rho_l(T)$ and $\rho_g(T)$ equations is proposed for joint calculation of $P,\ \rho,T$ - data along CC. The equations represent reliable experimental points in a region from 300 K up to the critical temperature. $P_s\,(T)$ is useful down to the triple point. The equations can be helpful to correct the standard tables [4] on CC in a low temperature region and in a vicinity of the critical point.

1. INTRODUCTION

The experimental P_s, T - data and values of densities ρ_l and ρ_g cover a wide region of temperatures. An attention was paid to the data array including results [1,2,3] which were devoted to experimental studies in the vicinities of the critical and triple points. The new data let us to review the vapor pressure equations and the equations for the densities of saturated liquid and saturated vapour received earlier [4,5,6].

We tested several models for $P_s\ (T),\ \rho_l(T)$ and $\rho_g(T)$ which had a form of a temperature expansion. They were built in different regions ΔT_w from a low working level T_w up to the critical temperature T_c ($\Delta T_w = T_c - T_w$). The length of ΔT_w was equal 74, 134 and 200 K. A relative RMS deviations in liquid and gas phases as a criterion of an approximation were calculated for the input. massive of selected measured points. The validity of models depends strongly on a value of the interval ΔT_w. The models consisted of two up to six terms were analyzed. The results of approximation with small RMS deviations was got when we used scaling model with three terms and ΔT_w was equal to 20...50 K. In the cases when the scaling part was add by analytical terms the combined models were useful in $\Delta T_w > 50$ K.

Scaling expressions include such parameters as critical exponents. We dealt with two methods of determination of the exponens for an approximation of input data. First method connected with Ising critical exponents. These values are determined theoretically. Some times there are a disadvantage of using this method to CC properties of one component liquids p [12,13]. The second way is helpful when the asymptotic region is within the experimentally attainable temperature interval. It gives an

opportunity to determine effective critical exponents during the fitting experimental input data. We try to find out advantages of the second way

2. THE SATURATION PRESSURE

According to the extended nonanalitical theory of critical phenomena an expression of $P_s(T)$ was chosen in the next form

$$ln(P_s/P_c) = B_{p0}(1 - 1/t) + B_{p1}\tau + B_{p2}\tau^{2-\alpha} + B_{p3}\tau^{2-\alpha+\Delta} + B_{43}\tau^3 + B_{p5}\tau^5, \qquad (2.1)$$

where $t=T/T_c$, $\tau=1 - t$, are the critical exponents, T_c and P_c the critical temperature and pressure, (B_{pi}) - adjustable coefficients

(B_{pi}) coefficients are to be determine under a statistical fitting. An approximation criterions are connected with deviations of experimental data from equation (2.1) expressed in the form

$$\delta P_i = 100 (P_{exp\,i} - P_i)/P_i, \qquad S_p = (\Sigma\delta P_i^2 / N)^{0.5}, \qquad (2.2)$$

where $P_{exp\,i}$ - an experimental value of P in i- point, P_i - a calculated value of P in i- point, S_p - a relative RMS deviation, N number of points of the start input massive or j - group devoted to a source.

The input massive consisted of selected experimental points including data [1,2,7-10]. The number of points was equal to 89, they covered ΔT_w=200 K. It is important to underline that the data [1,2] have given the first experimental value of the pressure P_{tr}=(420 ±10) Pa in the triple point at T = 169.86 K. The quality of the input massive is concluded in the fact that deviation of data near the triple point lay in the limit ± 4% and the same characteristic near the critical point equals to ± 0.2%. A relative RMS deviation for every j-group of points S^{exp}_{pi} was determined using the value recommended in j - source (some times it is the accuracy of the experiment) ore a local

approximation equation. The work with the massive of P_s,T - data showed that an approximation with criterion $S_p < 0.05\%$ delivered (S_{pj}) which are close to (S^{exp}_{pj}). This level of the criterion S_p was to be reached during the treaty.

A method of determination of (B_{pi}) coefficients was elaborated. It is needed on the firs step 1) to fix the value of zero coefficient B_{p0},T_c,P_c, α and Δ, 2) to calculate the other (B_{pi}) by a liner MSQ treaty of input points, 3) to calculate the criterions S_p and RMS deviation for every j-group of points S_{pi}. The second step of the routine depends on the results of the previous step. If analysis shows that criterion S_p are low enough and (S_{pj}) correlate with (S^{exp}_p) then routine is stopped. On opposite conditions a new fixed parameters are to chosen and the second step is to start. Using several steps the method leaded to an optimal decision.

During the study of the form (2.1) we estimated that the value of S_p depended on P_c and B_{p0} sufficiently. An influence of T_c on RMS S_p was modern. A small influence of α on RMS S_p was found. The P_c influence of Δ was smaller.

It is known that Kiselev [13] has used Ising values for the exponents α =0.1085 and $\Delta = 0.5$ to calculate $P_s(T)$. These values were taken on the first step of our treaty.

During the treaty when we selected fixed parameters the next interval of values was studied $P_c = (4.056 \pm 0.05)$ MPa and $T_c = (374.16 \pm 0.08)$ K.

The optimum combination of the parameters of (2.2) are presented in Table 1.

The value of P_c determined is rather close to the average critical pressure (4.059 ± 0.009) MPa that can be found in [4]. The value of T_c is close to the average figure (374.18 ± 0.07) K that can be found in [4]. T_c is lower than the standard value 374.21 K [4]. The critical exponents α was higher than Ising model value 0.1085. The correction

exponent Δ was taken due to Ising model. The equation given in [11] is one of the seldom scaling expressions for HFC 134a. The parameters of a crossover equation accepted in [11] are the next - P_c = 4.065 MPa and T_c = 374.274 K. It is seen that these values P_c and T_c are higher.

A comparison of the calculated saturation pressures data was done with directly measured points obtained by Blanke [2,3], Goodwin and co-workers [9], Magee and co-workers [10], Baehr and Tillner-Roth [8] and Weber [7]. with combined scaling pressure equation (2.1) in the range 240 K...T_c. A comparison was fulfilled with the international standard data obtained by Tillner-Roth and Baehr [4] and with calculated data obtained by Kiselev [11] using the program CREOS 97. The calculated saturation pressures coincide with data [11] in the limits 0.05% in the temperature interval 372...374.1 K.

A distribution of relative deviations are shown in Fig. 1,2. There are relative deviations δP_i for some groups of data in ΔT_w = 240 K in Fig. 1. The data [4] are represented here. In fig. 2 there are δP_i of data devoted to a low level of temperatures from 240 K down to the triple point temperature. Deviations of the standard data [4] are placed here. The deviation of the triple point pressure obtained by Blanke [3] is placed here.

RMS deviations (S_{pj}) for the groups are corresponded to (S^{exp}_{pj}) or are close the accuracy of the experiments. It appears that the data [1,2] are useful to correct the standard tables [4] in the low temperature region. The calculated value of P_{tr} is equal 412 Pa that is in a good agreement with the accuracy (±10 Pa) of the experiment [1] and higher than the value 390 Pa [4].

3. THE DENSITIES OF THE SATURATED LIQUID AND VAPOUR

According to the extended nonanalitical theory of critical phenomena [13] the order parameter f_s and the diameter of CC f_d can be expressed in some temperature interval by expansions

$$f_s = (\rho_l - \rho_g)(2\rho_c)^{-1} = B_{s0}\tau^{\beta} + B_{s1}\tau^{\beta+\Delta} + B_{s2}\tau^{\beta+2\Delta}, \quad (3.1)$$

$$f_d = (\rho_l + \rho_g)(2\rho_c)^{-1} - 1 = + B_{d0}\tau^{1-\alpha} + B_{d2}\tau^{1-\alpha+\Delta} + B_{d0}\tau^{1-\alpha+2\Delta}, \quad (3.2)$$

where ρ_c, α, β and Δ denote the critical density and the critical exponents, (B_{si}) and (B_{di}) - amplitudes.

The amplitudes (B_{si}) and (B_{di}) are to be determine under a statistical fitting.

It is known one way to determine the exponents α, β and Δ from a theoretical model as it done in [11,13]. In the case there are taken as $\beta=0.325$, $\alpha=0.1085$ and $\Delta=0.5$. The second method considers the exponents α and β as adjustable parameters. The value of α and β have to be determine in a procedure of experimental data approximation. The same way is applied for calculation of amplitudes (B_{si}) and (B_{di}), ρ_c and T_c. Interesting results have been got in [12,13] where the authors used the second method in a wide temperature region - $\Delta T_w=100..300$ K. During the investigation we tested these two methods for an approximation of HFC134a points. An analysis of the results has shown that the model (3.1,3.2) with effective values of parameters can be adequate to experimental data in $\Delta T_w=74$ K if there are three terms in the expansions (3.1,3.2). The expressions (3.1,3.2) with three terms are named hear as Model 1 of extended scaling laws.

One more model was checked with the aim to express experimental data in $\Delta T_w > 74$ K. Two extra analytical terms τ^2 and τ^3 were added in (3.1,3.2) and the rescieved expressions were named combined equations - Model 2

$$f_s = (\rho_l - \rho_g)(2\rho_c)^{-1} = B_{s0}\tau^\beta + B_{s1}\tau^{\beta+\Delta} + B_{s2}\tau^{\beta+2\Delta} + B_{s3}\tau^2 + B_{s4}\tau^3 , \qquad (3.3)$$

$$f_d = (\rho_l - \rho_g)(2\rho_c)^{-1} - 1 = B_{d0}\tau^{1-\alpha} + B_{d1}\tau^{1-\alpha+\Delta} + B_{d2}\tau^{1-\alpha+2\Delta} + B_{d3}\tau^2 + B_{d4}\tau^3 . \qquad (3.4)$$

With the help of known Models 1 and 2 numerical values of densities on CC can be determine by the expressions

$$\rho_l = (f_d - f_s + 1)\rho_c, \rho_g = (f_d + f_s + 1)\rho_c . \qquad (3.5)$$

The amplitudes (B_{si}) and (B_{di}) are to be determine under a statistical fitting. An approximation criterions used are connected with deviations of experimental data. Relative individual and RMS deviations of experimental points from equations (3.1,3.2,3.3,3.4) were calculated for the start massive (S) and every j-group of points (S_j)

$$\delta\rho_{gi} = 100\ (\rho_{g\ exp\ i} - \rho_{gi})/\rho_{gi} , \qquad S_g = (\Sigma\delta\rho_{gi}^2 / N)^{0.5} ,$$

$$\delta\rho_{ei} = 100\ (\rho_{l\ exp\ i} - \rho_{li})/\rho_{ei} , \qquad S_e = (\Sigma\delta\rho_{li}^2 / N)^{0.5},$$

where $\delta\rho_{gi}, \delta\rho_{ei}$ - relative deviations of the vapour and liquid densities in i - point, $\rho_{g\ exp\ i}$ and $\rho_{l\ exp\ i}$ - experimental values of the densities in i - point, ρ_{gi} and ρ_{li} calculated values of the vapour and liquid densities in i - point, N - number of points taken in to a consideration - number of points of the input massive or j-group, S_g, S_e - relative RMS deviations of the vapour and liquid densities.

The input massive (ρ_l, ρ_g, T) consisted of selected experimental points including data [1,2,3, 7,14 - 17]. The number of points was equal to 153, they covered ΔT_w=134 K. It is important to remark that the data [3] gives the experimental value in the interval ΔT_w=2 K where a big scattering of points gives some problems. A relative RMS deviation for every j-group of points $S^{exp}_{\rho\ j}$ was determined using the value recommended in j - source (some times it is the accuracy of the experiment) ore a local approximation equation. The quality of the input massive is the next: scattering of

points of the liquid and the same in the vapour are differ; RMS deviation $S_e \cong 0.1\%$ and RMS deviation $S_g \cong 0.5\%$. The problem of approximation is to fined a compromise between two criterions. The work with the massive of (ρ_l, ρ_g, T) - data showed that an approximation with criterion $S_e \cong 0.1\%$ and $S_g \cong 0.5\%$. delivered $(S_{\rho j})$ which are close to $(S^{exp}_{\rho j})$. This level of the criterions S_e and S_g was to be reached during the treaty.

The fixed parameters as ρ_c, T_c, α, β and Δ of Model 1,2 can be taken from literature sources or determine previously. The other free parameters - amplitudes (B_{si}) and (B_{di}) are to be determine under a treatment. It is an usual schema [14]. A method of determination of parameters of the equations (3.1,3.2,3.3,3.4) was produced. As in the case of P_s (T) treaty the firs step was to fix the values of leading amplitudes B_{so}, B_{do} in addition to $\rho_c, T_c, \alpha, \beta$ and Δ. The other (B_{si}, B_{di}) were to be calculated by the liner MSQ treaty of input points. The criterions S_e and S_g and deviations for groups $(S_{\rho j})$ were to be determine. The second step of the routine depends on the results of the previous step. If analysis showed that criterion S_e and S_g were low enough and $(S_{\rho\ j})$ correlated with $(S^{exp}_{\rho j})$ then routine was stopped. On opposite site a new fixed parameters were to be chosen and the second step was to start. Using several steps the method leaded to an optimal decision.

An elaborated statistic routine gave a possibility by changing step by step the leading amplitudes B_{so}, B_{do} to fined Model 1 with the next properties: 1) expansions (3.1, 3,2) with two terms fit adequately the points in $\Delta T_w = 10$ K, 2) expansions (3.1, 3.2) with three terms fit adequately the points in $\Delta T_w = 74$ K. A model with these properties corresponds to a theoretical statement that the second term in (3.3,3.4) is to play a roleof the firs correction term and the second term is to play a role of the third correction one.

When using the routine for Model 2 it is possible to get just the same properties of the equations: 1) expansions (3.5, 3.6) with two terms fit adequately the points in $\Delta T_w \cong$ 10 K, 2) expansions (3.5, 3.6) with three terms fit adequately the points in $\Delta T_w = 74$ K.. The form of Models 1, 2 satisfied to the criterion let us say that Model 2 include coefficients of Model 1 as a scaling kernel. The extra terms play a role of correction members in $\Delta T_w > 74$ K.

On every step of the routine the scaling function $\psi_{l,j}$ is investigated. It has the form

$$\psi_{l,j} = \left| (\rho_{l,g} - \rho_g)(\rho_c \tau^\beta)^{-1} \right| = \left| \pm B_{s0} + B_{d0} \tau^{1-\alpha-\beta} \pm B_{s1} \tau^{\Delta-\beta} + \dots \right|. \qquad (3.8)$$

Due to (3.8) the next criteria can be estimated: in some region ΔT_w there is $\psi_{l,j}$ that is to be linear and symmetrical to the amplitude B_{s0}. The form of the scaling function is an important criteria of an optimal decision for Models 1,2.

When we build Model 2 the amplitudes of Model 1 are determine automatically. For a detailed analyses of the decision some additional characteristics are calculated in different ΔT_w: 1) for Model 1 - S_e and S_g in $\Delta T_w = 74$ K, S_{pe} and S_{pg} in $\Delta T_w = 134$ K, 2) for Model 2 - S_{pe} and S_g in $\Delta T_w = 74$ K, S_e. In the case when the characteristics of the Models coincide it is possible to conclude that Model 2 include coefficients of Model 1 as a scaling kernel.

Selecting parameters for (3.3-3.6) we accepted values which reported Yata [3]: ρ_c = 511 kg/m^3, T_c = 374.107 K and β = 0.348. These figures were chosen as fixed parameters in the firs step of the routine. A sequence of steps let us determine numerical ingredients for Model 2 which are placed in Table 2.

The value of ρ_c determined is rather close to the value $\rho_c = (511 \pm 3)$ kg/m^3 reported in [1,18]. ρ_c is lower than $\rho_c = 511.95$ kg/m^3 recommended in [4]. ρ_c is lower than $\rho_c = 505.0$ kg/m^3 used in [11].

The value of $T_c = 374.107$ K is a little lower than the average data (374.18 ± 0.07) K and $T_c = 374.16$ K that was determine during our $P_s(T)$ determination.

The determined value of $\beta = 0.349$ is rather close to the start value [1] and to the results [12,13] related to other substances and to the date [14] related to HFC134a. It is higher than Ising value $\beta=0.325$.

The next values of the criterions of the approximation were found: 1) for Model 1 - $S_e = 0.15\%$ and $S_g = 0.37\%$ in ΔT_w=74 K; 2) for Model 2 - $S_e = 0.14\%$ and $S_g = 0.38\%$ in ΔT_w=74 K; $S_e = 0.13\%$ and $S_g = 0.71\%$ in ΔT_w=134 K. The criterions confirm that the characteristics of Model 1 coincide with those of Model 2 in ΔT_w=74. It is possible to conclude that Model 2 include coefficients of Model 1 as a scaling kernel. The compromise found between two criterions is quite acceptable. RMS deviations $(S_{\rho j})$ for the groups are corresponded to $(S^{exp}_{\rho j})$ or close the accuracy of the measured data.

An analysis of the scaling function showed that its form suits satisfactorily to a theoretical prediction.

A comparison of calculated densities on the coexisting curve was done with directly measured points obtained by Yata [1], Fakushima and co-workers [15] Kabata and co-workers [14], Weber [7], Niesen [17], Blanke [2,3] with combined scaling density equation (3.3,3.4). A comparison was fulfilled with the international standard data obtained by Tillner-Roth and Baehr [4] and with calculated data obtained by Kiselev [11] using the program CREOS 97. RMS deviations $S_{\rho j}$ for the group [4] are

equal to 0.076% in the liquid and 0.27% in the vapour in the interval 240...372 K. There are higher deviations in ΔT_w=2.1 K. Calculated data [11] are lower $\delta \rho_l$ = -0.5.. - 1.5 % in the liquid and higher $\delta \rho_g$ = 1... 1.5 % in the vapour in ΔT_w=2 K

A distribution of relative deviations are shown in Fig. 3,4 in ΔT_w = 74 K. There are relative deviations $\delta \rho_{gi}$ for some groups of experimental data for the saturated liquid in Fig. 3. The data [4] are represented hear too. In fig. 3 there are $\delta \rho_g$ of the data in the vapour. Deviations of the points [4] are placed her too.

The combined equations P_s (T), $\rho_l(T)$ and $\rho_g(T)$ discussed higher were got independently from each other. A priory it is impossible to predict what kind of adjustable parameter $(\alpha, T_c, \rho_c, ...)$ will be optimal for one property, even more it is impossible to estimate a priory the values of effective α and T_c which have to be used jointly in the saturated pressure equation and in the CC density equations. We found out the next compromise value of T_c = 374.13 K and α = 0.15 for a joint system of combined scaling equations. The system is preferable if it is needed to calculate some combination of properties which include P_s, T, ρ_l, ρ_g dP_s/dT a. o. The critical parameters and exponents, coefficients and amplitudes of equations included in the system were determine with the help of the routines discussed higher. The characteristics are placed in Table 3.

A comparison of the properties on CC calculated with the help of the joint system was done with directly measured points obtained in the manner that expressed higher. The approximation characteristics of the system are similar to those of the optimal equations described higher. Some discrepancy in calculated properties takes place

because of the difference in fixed parameters: the critical temperature, pressure and exponent α.

ACKNOLEGMENTS

REFERENCES

1.   W. Blanke, G. Klingenberg, R. Weiss, *Int. J. Thermophys*. 16: 1143 (1995).

2.   W. Blanke, R. Weiss, in *PTB Bericht*, (Braunschweig, Germany, Februar 1996), p. 1-25

3.   J. Yata, in *Proceedings of the 1st Workshop on thermochemical, thermodynamic and transport properties of halogenated hydrocarbons and mixtures,* (Pisa, Itali, 1999), p. 120

4.   R. Tillner-Roth, H.D. Baehr, *J. Phys. Chem. Ref. Data, 23,* p. 657-728 (1994).

5.   A.V Dobrokhotov., E.E. Ustjuzhanin, B.F. Reutov, *J. High Temperature-High Pressure, 31,* p.375 - 380 (1999).

6.   E.E. Ustjuzhanin, B.F. Reutov, A.B. Lobanov, in *Proceedings of the 1st Workshop on thermochemical, thermodynamic and transport properties of halogenated hydrocarbons and mixtures,* (Pisa, Itali, 1999), p.68.

7.   L.A. Weber *Int. J. Thermophys*. 10: p. 617 (1989).

8.   Baehr H. D., Tillner-Roth R *J. Chem. Thermodynamics*, V.23, 1991, p. 1063-1068.

9. Goodwin A.R.H., Defibaugh D. R., Weber L. A., *Int. J. Thermophys*. 10: 626 (1993).

10. J.W. Magee, J.B. Howler, *Int. J. Refrig.*,V.15, N 6, p.362-364, (1992).

11. S.B. Kiselev, M.L. Huber, *Int. J. Refrig.*, V.21, N 1, p. 64-76 (1998)

12 E.T. Shimanskaya, Yu. I. Shimansky and A.V. Oleinikova, *Int. J. Thermophys*. 17: 641 (1996)

13. V.A. Rabinovich, Yu.E. Sheludiak, *Thermophys. of High Temperture* (rus) V. 33, N4, p. 546-552, (1995).

14. Y. Kabata , S. Tanikawa, M. Uematsu, K. Watanabe, *Intern. J. Thermoph.* <u>10:</u> 605 (1989).

15. M. Fukushima, K. Watanabe., T. Kamimura *Trans. of the JAR*. V.7, N2, p.85-95, (1990).

16. H. D. Baehr, R. Tillner-Roth *J. Chem. Thermodynamics*, V.25, p 1063-1068, (1993).

17. V. G. Niesen, L.J. Van Poolen, S.L. Outcalt, C. Holcomb, *Fluid Phase Equil*, 19, p. 163-167, (1993).

Table 1 Vapour pressure equation

Critical parameters and exponents

P_c /MPa	T_c /K	α	Δ
4.056	374.16	0.13	0.5

Coefficients

B_{p0}	B_{p1}	B_{p2}	B_{p3}	B_{p4}	B_{p5}
1	-6.617472	4.832822	-23.136551	10.850666	-45.108741

Table 2. Equations for densities on the coexisting curve

Critical parameters and exponents

ρ_c / kg/m^3	T_c /K	α	β	Δ
510.5	374.107	0.15	0.349	0.5

Amplitudes

B_{s0}	B_{s1}	B_{s2}	B_{s3}	B_{s4}
2.1086	1.070546	-0.728417	-0.080814	0.390958
B_{d0}	B_{d1}	B_{d2}	B_{d3}	B_{d4}
0.494	-0.067772	-0.351772	-0.081399	0.383732

Table 3. The system of combined scaling equations

Critical parameters and exponents

P_c /MPa	ρ_c / kg/m^3	T_c /K	α	Δ
4.056	509.5	374.13	0.15	0.5

Coefficients of the vapour pressure equation

B_{p0}	B_{p1}	B_{p2}	B_{p3}	B_{p4}	B_{p5}
1	-6.657749	5.215287	-23.195393	10.622101	-45.208388

Amplitudes

| B_{s0}	B_{s1}	B_{s2}	B_{s3}	B_{s4}
2.1541	0.494035	0.011263	0.056136	-0.297321
B_{d0}	B_{d1}	B_{d2}	B_{d3}	B_{d4}
0.612	-0.15665	-0.301785	-0.060392	0.349387

FIGURE CUPTIONS

Fig. 1 Percentage deviations of the experimental saturation pressures obtained by Tillner-Roth and Baehr [4], Blanke [2,3], Goodwin and co-workers[9] , Magee and co-workers[10], Baehr and Tillner-Roth [8] and Weber [7] with combined scaling pressure equation (2.1) in the range 240 K...T_c

Fig. 2 Percentage deviations of the experimental pressures obtained by Tillner-Roth and Baehr [4], Blanke [2,3], Goodwin and co-workers [9] and Magee and co-workers [10] with combined scaling equation (2.1) in the range T_{tr}... 240 K.
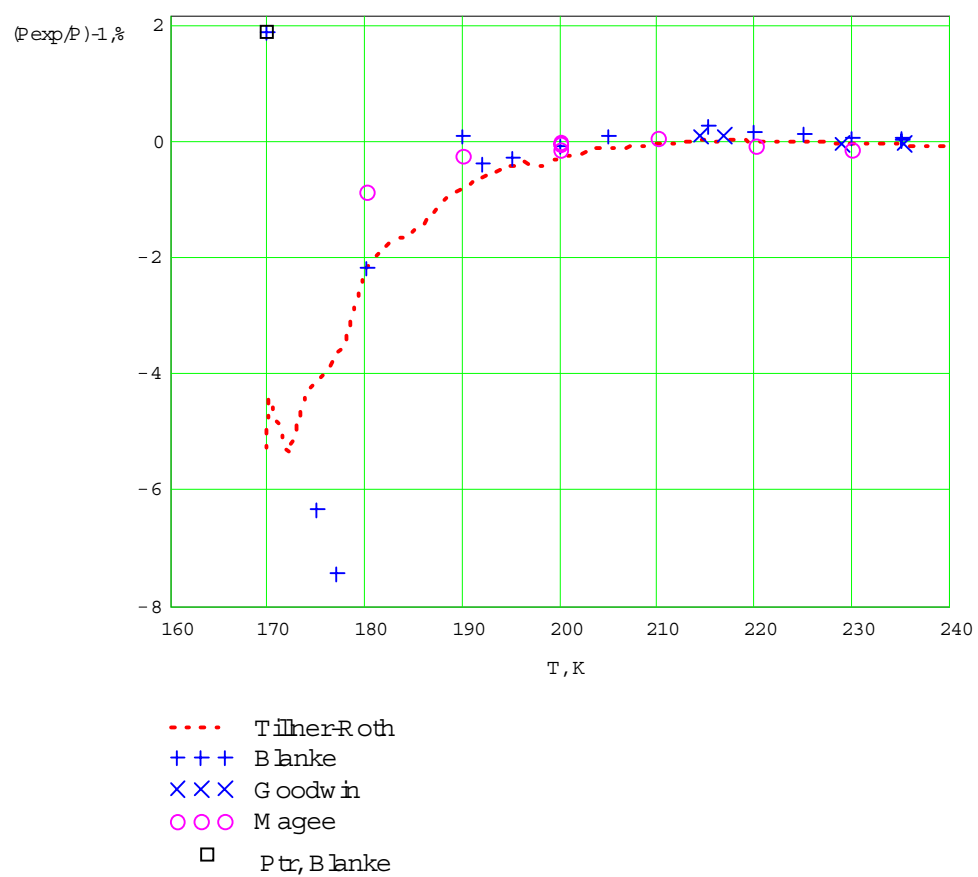
Fig. 3 Percentage deviations of the experimental densities of the vapour obtained by Yata [1], Fakushima and co-workers [15], Tillner-Roth and Baehr [4], Kabata and co-workers [14], Weber [7], Niesen [17], Blanke [2,3] with combined scaling density equation (3.3,3.4) in the range 280 K ...T_c.

Fig. 4 Percentage deviations of the experimental densities of the liquid obtained by Yata [1], Fakushima and co-workers [15], Tillner-Roth and Baehr [4], Kabata and co-workers [14], Weber [7], Niesen [17], Blanke [2,3] with combined scaling density equation (3.3,3.4) in the range 360 K ...T_c.
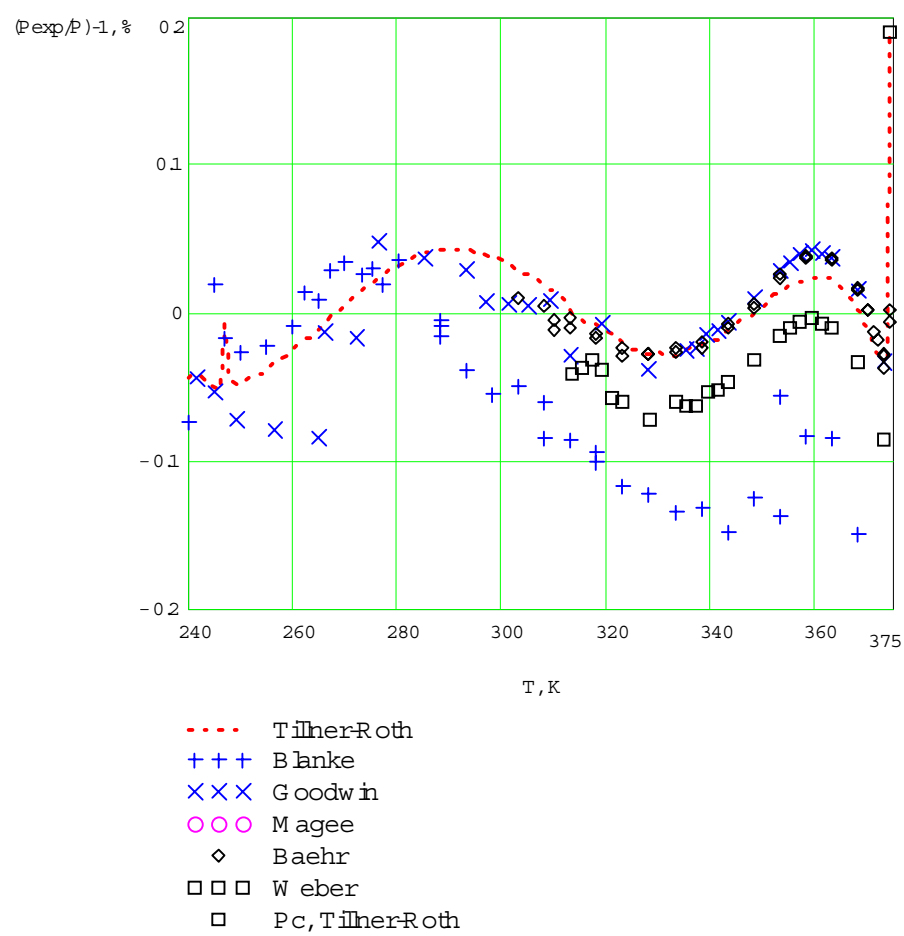
Fig. 1

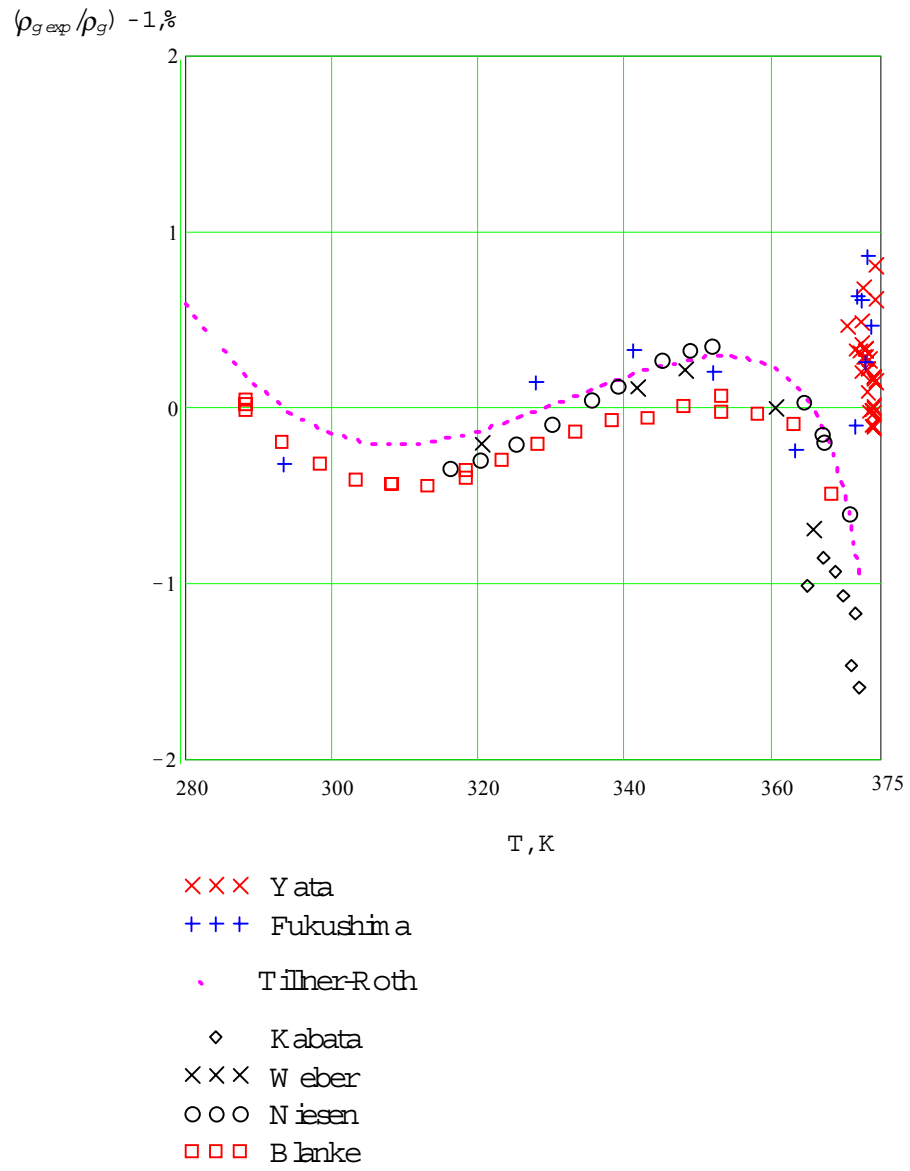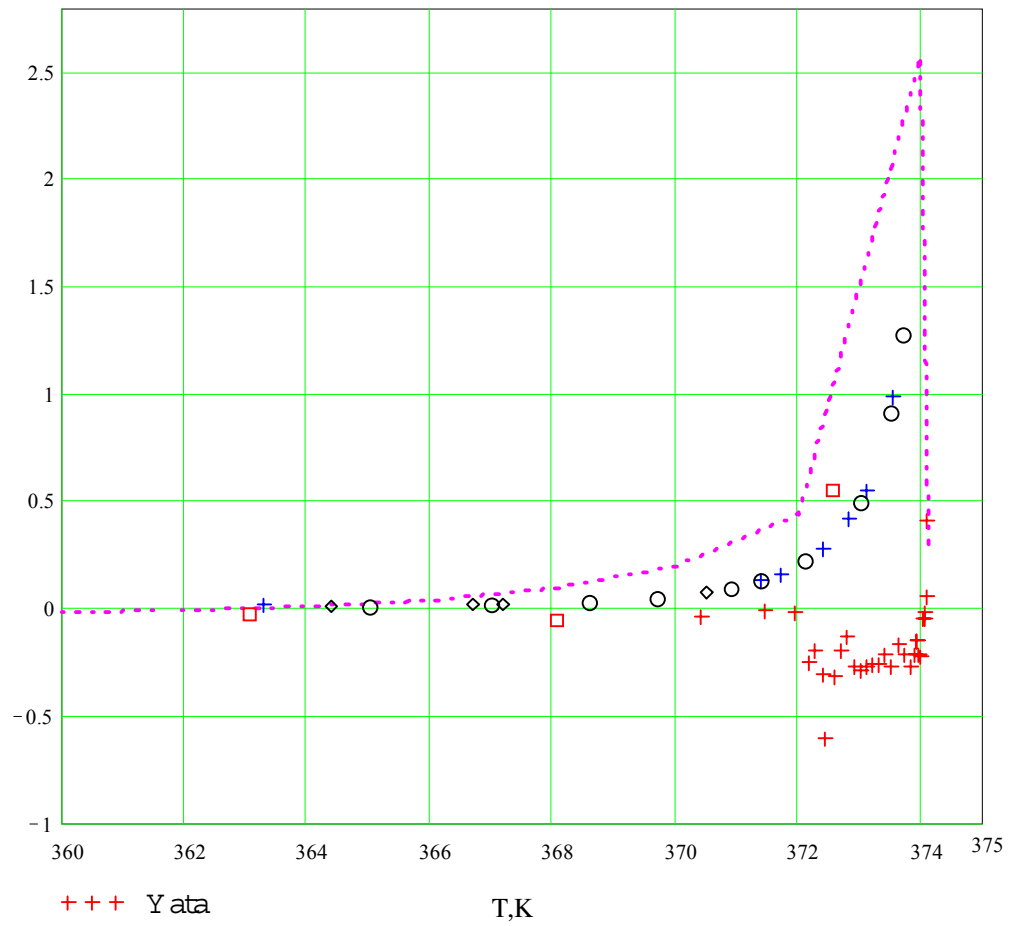Ustjuzhanin E.   Fig. 1

Ustjuzhanin E.   Fig. 2

$(\rho_{g\,exp}/\rho_g) - 1, \%$

T, K

×× × Yata

+ + + Fukushima

. Tillner-Roth

◇ Kabata

××× Weber

∘∘∘ Niesen

☐☐☐ Blanke

Ustjuzhanin E.   Fig. 3

$(\rho_{1exp}/\rho_1) - 1, \%$

+ + + Yata
+ + + Fukushima
—   Tillner-Roth

o o o Kabata
  ◇   Niesen
□ □ □ Blanke

Ustjuzhanin E.   Fig. 4